ANALYSIS OF THE BENTHIC MACROINVERTEBRATE COMMUNITY STRUCTURE FOR ASSESSMENT OF WATER QUALITY OF THE DES MOINES RIVER

An abstract of a Thesis by
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The problem. An evaluation of the water quality of the Des Moines River in the Des Moines, Iowa area was accomplished by sampling and analyzing the benthic macroinvertebrate community.

Procedure. Artificial substrates at five stations collected macroinvertebrates. Community structure was analyzed using species diversity indices. Species diversity ($\bar{D}$) and redundancy (R) values were used to calculate standardized distance (S.D.) values. These indices were analyzed using standard statistical tests of significance.

Findings. An analysis of variance for standardized distance (S.D.) values demonstrated significant difference for sampling dates and location of stations. When adjusted for current velocity, no significant difference was detected for station locations, but significance over time was retained. Mean value for species diversity was 2.19. Macroinvertebrate samples demonstrated seasonal distribution.

Conclusions. Current velocity appeared to be a major factor controlling colonization of macroinvertebrates in this study. The mean species diversity value indicated the Des Moines River is mildly polluted. Standardized distance (S.D.) values appear to be more meaningful than species diversity ($\bar{D}$) alone in assessing community structure.

Recommendations. The main recommendation for future study is to compare benthos sampled with artificial substrates in different current velocities at the same location.

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INTRODUCTION AND LITERATURE REVIEW

Although water quality has been traditionally assessed in purely chemical terms by measuring dissolved oxygen (D.O.), biological oxygen demand (B.O.D.), suspended solids, and ammonia, pollution is essentially a biological phenomenon in that its primary effect is on living things. Measurable chemical or physical properties of an effluent can only allow one to guess at the effect it is likely to have on the living things in a river; only direct biological study can actually determine what these will be. Biological investigation reveals the effects of intermittent pollution or the result of a single discharge of a toxic substance, which the chemist may miss altogether. The advantages of biological investigation are in the fact that the animals and plants provide a more or less static record of both present and past conditions and they will not quickly change with a fluctuation of the effluent.

All categories of living creatures are useful in the study of pollution (Hynes, 1966). However, there has been some disagreement among biologists as to which type of organism is most indicative of pollution. Fishes are the least satisfactory because they are difficult to see or catch and are less abundant than smaller organisms. They are also very mobile, so they often occur far away from their normal habitat. Bacteria, algae, rooted plants and

invertebrates on the other hand are less mobile, more abundant and easier to collect, so they offer greater possibilities for study.

There are, however, several disadvantages in using microorganisms for the assessment of pollution. In the first place they are not easy to sample quantitatively unless they can be induced to grow on slides. Secondly, most microorganisms must be examined alive or they are unidentifiable. This means that laboratory facilities must be readily available, because even tolerant organisms will not live for long in grossly polluted water once it is allowed to stagnate in jars or collecting tubes. Thirdly, it is very important, especially with protozoans, that accurate identifications be made. Within some genera, different species occur under quite different water quality conditions. Specific identification of these organisms is far from easy and requires special training. Microorganisms indicate little more than can be determined by examination of such readily identifiable organisms as sewage fungus and algae which have the advantage of remaining identifiable even after preservation in formalin. But, the knowledge of algae is too limited to be used for the study of very mild pollution. Very little is known about the reaction of microorganisms to pollution which is not simply organic, nor is enough known about them to be of use in the assessment of very mild pollution.

Macroinvertebrates offer technical advantages in that

they are easy to collect and identify after preservation, so samples can be dealt with in a laboratory removed from the sampling point. They are also particularly useful for the assessment of toxic substances and mild pollution of all kinds. However, there are several other reasons why bottom fauna are studied: (1) many species are extremely responsive to pollution; (2) bottom fauna usually have a complex life cycle with aquatic stages of a year or more; and (3) since they have an attached or sessile mode of life and are not subject to rapid migrations, they serve as natural monitors of water quality.

Bottom fauna may be collected by a variety of techniques that produce both quantitative and qualitative information. In a pollution survey, it is usually advisable to collect both types of data. Qualitative sampling determines the variety of species of bottom fauna while quantitative sampling is performed to observe changes in predominance or abundance. Macan (1958), Cummins (1962), and Hynes (1970) discussed types of apparatus and methods of quantitative sampling of benthos in running water.

The use of artificial substrates to collect aquatic organisms is increasing because they offer several advantages over conventional sampling techniques. The use of artificial substrates may provide a rapid and effective method of monitoring water quality in streams (Hilsenhoff, 1969). Conventional sampling techniques require that the

operator put forth the same amount of effort at each station before comparisons can be made among the organisms collected. This means that the operator must sample the same types of habitats with the same degree of efficiency at each station. This requires a subjective judgment on the part of the operator and errors can result. However, artificial substrates eliminate some of this subjectivity and offer sites where bottom fauna can colonize. Therefore, the same type of habitats are open for colonization by the organisms at each station.

The use of artificial substrates is not new. Moon (1935) placed trays of rocks in a lake; Macan (1958) however, found that this did not work well in streams. Britt (1955) and Mundie (1956) placed pieces of concrete in lakes, and Hester and Dendy (1962) designed an artificial substrate from tempered hardboard. Wene and Wickliff (1940) used baskets of hardware cloth filled with medium-sized or small stones, and Scott (1958) used hardware cloth to confine sticks, stones, and other types of substrate. Henson (1965) described a cage of hardware cloth and angle-iron used to survey the macroinvertebrate fauna of large rivers. Mason, Anderson and Morrison (1967) suspended "Bar-B-Q" baskets filled with approximately 9 kg of limestone from floats to collect samples from large rivers. Little effort was made by any of these workers to prevent the escape of animals while the samplers were retrieved. Bull (1968) placed

stone substrates on river bottoms in collapsible wire baskets surrounded by a fine mesh bag so that they could be retrieved without the organisms escaping. Floating artificial substrate samplers are commercially available. These samplers have a plastic web as a synthetic habitat for colonization by aquatic organisms. Dickson and Cairns (1972) determined that these samplers are valuable for qualitative data but not quantitative data.

Perhaps the simplest type of artificial substrate is a wire basket containing rocks (Mason, Anderson and Morrison, 1967) or spheres. Organisms are carried to the sampler by water currents and colonize the artificial substrate. Jacobi (1971) tested basket samplers with spherical artificial substrates consisting of concrete, styrofoam and wood. Concrete was determined to be the best material to use on the basis of its durability against wear and stability against displacement by a strong current.

Basket samplers compare very favorably with other types of samplers. Anderson and Mason (1968) collected a larger number and variety of immature aquatic insects with the basket sampler than with the Petersen Dredge. Fuller (1971) collected more genera with the basket sampler than the multiple plate sampler. Organisms dominant on natural substrate sampled with the Surber sampler have been found to be predominant on spheres contained in the basket sampler (Jacobi, 1971).

The basket sampler is a practical device for collecting benthic macroinvertebrates in large streams. It is easy to install and the collections can be made by persons of varying experience and training. The sampler is durable, corrosion resistant and inexpensive. The capability of the basket sampler to collect a more complete representation of benthic macroinvertebrates is of great value in water pollution investigations (Dickson, Cairns and Arnold, 1971).

Community structure of benthic macroinvertebrate populations has frequently been used to evaluate water quality conditions in streams. Of the two approaches typically used in the study of natural communities, one emphasized biomass and production and is concerned with assemblages of organisms in terms of matter and energy. The second approach emphasizes community structure and analyzes communities as complexes of individuals belonging to different species with definite ecological requirements. Community structure has been described in terms of species frequency, species per unit area, spatial distribution of individuals and numerical abundance of species (Hairston, 1959).

Diversity indices permit summarization of large amounts of information about numbers and kinds of organisms (Patten, 1962). Such parameters express the distribution of individuals among species. According to Hairston (1959), the first important attempt to interpret animal community structure from the relationship between numbers of individuals and

species was that of Fisher, Corbet and Williams (1943). Fisher concluded that the logarithmic series provided an adequate description of the data, and he proposed a constant, α, as an expression of diversity. Preston (1948) stated that the frequency distribution of an animal population is nearer a lognormal distribution; that is, frequency distributions of random samples of ecological assemblages approximate the form of a normal curve drawn on a logarithmic base.

Diversity indices are mathematical expressions that summarize numerical information about numbers and kinds of organisms. They are of value in comparing different communities. Hairston (1959) described various functions which have been used to show how species and individuals in a community are related. Wilhm and Dorris (1966) used diversity indices to evaluate the effect of organic enrichment. A number of diversity models have been proposed (Gleason, 1922; Fisher et al, 1943; Preston, 1948; Simpson, 1949; Yount, 1956; Hairston, 1959; Odum, Cantlon and Kornicker, 1960; Patten, 1962). Diversity indices derived from the information theory are in wide useage for summarization for biotic community structure. Recently, Wilhm (1967, 1968, 1970a, 1970b, 1972) and Cairns et al (1968, 1969, 1971) have been prominent in publishing material about the structure of aquatic communities.

For routine pollution control work, recognition of simple external differences such as color, size, and shape

is sufficient to determine the number of kinds of bottom fauna present in a collection to provide reliable interpretive data. Simple sorting of organisms into obvious groups closely approximates the number of different kinds of organisms present. The assignment of a scientific name is not essential (Wilhm and Dorris, 1966). Precise identification of organisms by species requires a specialist in taxonomy and very often provides very little additional information. An F test value showed that no significant difference existed at the 0.05 significance level in the number of kinds of bottom fauna as determined by a specialist and nonbiologist (Cairns and Dickson, 1971). This seems to indicate that most bottom fauna organisms are fairly easily divided into recognizable entities by nonbiologists.

The object of this study was to assess the water quality of the Des Moines River in the metropolitan area of Des Moines, Iowa, by sampling benthic macroinvertebrates at five stations with artificial substrates and analyzing this community with species diversity indices to detect changes in the aquatic community structure.

MATERIALS AND METHODS

The Des Moines River, an important western tributary of the Mississippi and the longest stream in Iowa, rises in the southwestern part of Minnesota near the town of Pipestone.

From its source the river flows 535 miles in a southeasterly direction until it eventually joins the Mississippi two miles south of Keokuk, Iowa. Above Humboldt, in central Iowa, the river is known as the West Fork Des Moines River. The East Fork and the Raccoon River are the major tributaries. For a distance of 25 miles above its mouth the river serves as the boundary between Iowa and Missouri. The Des Moines drains an area of 15,807 square miles of rich, glaciated farm land. From its source to its mouth the river falls a total of 1,375 feet, or about 2.6 feet per mile; this rate is nearly constant throughout its entire course.

Among the effluents which enter the river from the metropolitan Des Moines area (population 286,101 - U. S. Bureau of the Census, 1972), are those from the Des Moines sewage treatment plant (STP) and the Iowa Power and Light Company (IPALCO). The sewage treatment plant contains bar screens, wet well, surge tank, grit chambers, grease skimmer, pre-aeration tanks, dosing chambers, internal trickling filters, internal clarifiers, trickling filters and final clarifiers. In November 1970, approximately 35 million gallons of sewage were treated per day. The plant is 88-92% efficient and the B.O.D. of the effluent entering the Des Moines River is 30-40 parts per million (ppm). River water is used by IPALCO to cool generators. The temperature of the IPALCO effluent entering the river is usually at a higher temperature than the water drawn from

the river; however, precise information about IPALCO was not obtained. The selection of sample sites was based on the location of STP and IPALCO and their probable effects on the receiving water. See Figure 1 and Table 1 for descriptions of the study area and sampling sites.

Sampling began in May 1971 and was accomplished by using a float unit which supported artificial substrate. Each float unit consisted of a 5.0 gallon (18.9 liter) can with a threaded rod, $\frac{1}{2}$ in by 18 in (1.27 cm by 54.72 cm), inserted through a center opening at each end of the can. The threaded rod was held in place at each end of the can with a $1\frac{1}{4}$ in by 12 in (3.18 cm by 30.48 cm) section of strap steel, a washer and nut. To each end of the threaded rod, a ring and eyebolt, $\frac{1}{2}$ in by 4 7/8 in (1.27 cm by 12.38 cm) was attached with a rod coupler. The cans were filled with polyurethane foam to increase flotation and to prevent damage by vandalism. Some floats were anchored with a $\frac{1}{4}$ in (0.64 cm) cable connected to one or two 40-pound mason foundation blocks. Other floats were attached to bridge supports with $\frac{1}{4}$ in cable.

Two barbeque baskets were suspended from each float. See Mason, Anderson and Morrison (1967) for a complete description of the basket. Each basket had a 5/16 in by 4 in (0.79 cm by 10.16 cm) eyebolt fastened to one end. Just below the surface of the water, one basket was attached to the upstream ring and eyebolt by a double snap. One meter

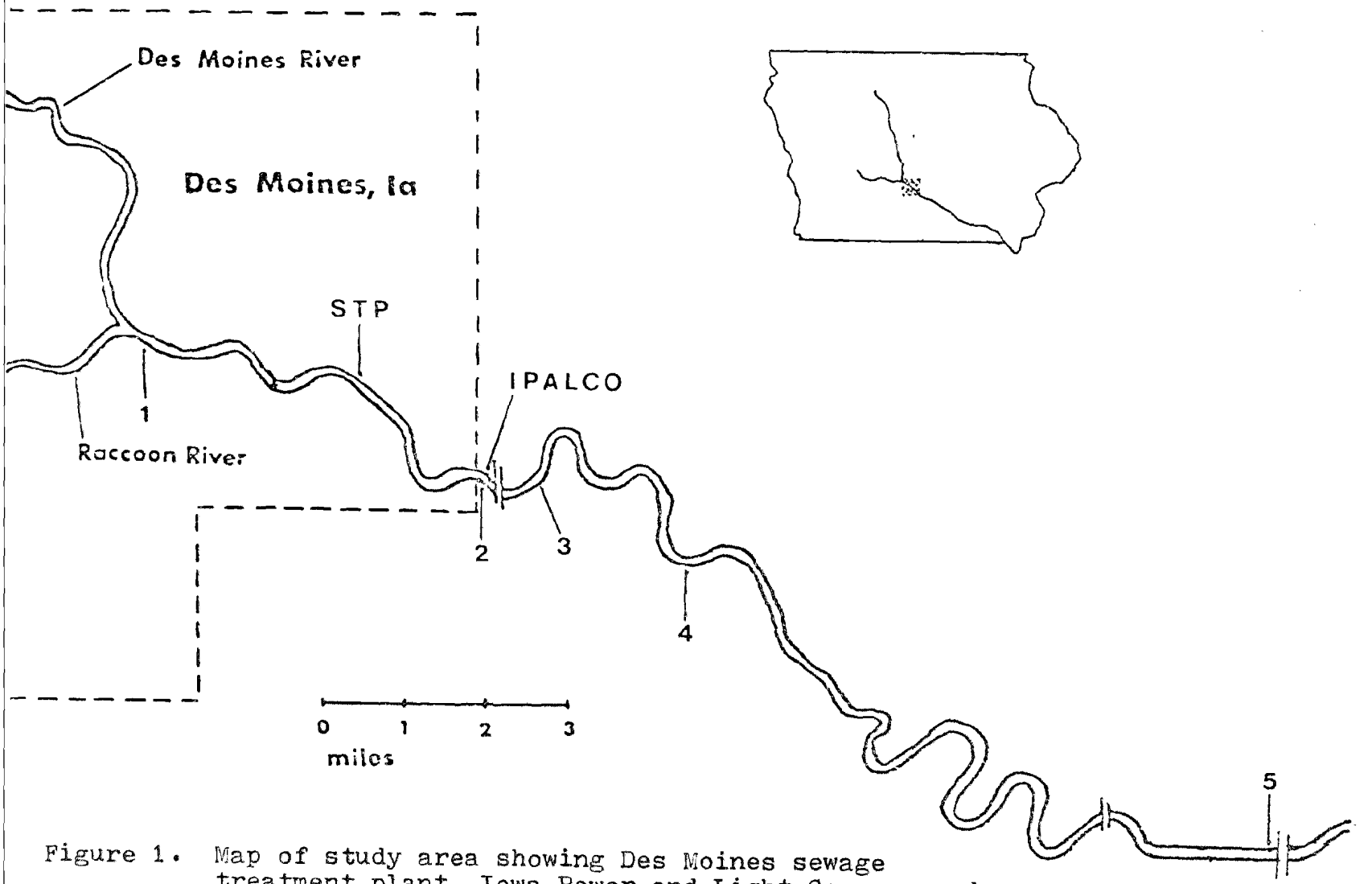

Figure 1. Map of study area showing Des Moines sewage treatment plant, Iowa Power and Light Company and five sampling stations.

Table 1. Location and description of sampling stations.

Station	Miles*	Description
1	199.7 (321.5 km)	S. E. 6th St. Bridge, 0.5 mile upstream from S. E. 14th St. Bridge; 2.8 miles upstream from STP; 5.6 miles upstream from IPALCO
2	194.2 (312.7 km)	Old railroad bridge support, 0.1 mile upstream from State Route 46 (IPALCO) Bridge; 2.7 miles downstream from STP; 0.05 mile upstream from IPALCO
3	193.5 (311.5 km)	0.6 mile downstream from State Route 46 Bridge; 0.6 mile downstream from IPALCO; 3.4 miles downstream from STP
4	190.6 (306.9 km)	3.5 miles downstream from IPALCO; 6.3 miles downstream from STP
5	176.6 (284.3 km)	Runnells Bridge, County Route 316; 17.5 miles downstream from IPALCO; 20.3 miles downstream from STP

*Miles above junction with Mississippi River.

below the surface of the water, the second basket was suspended by a 3/4 in (1.90 cm) galvanized swivel snap which in turn was connected to the downstream ring by ¼ in cable secured with cable clamps. Each basket was filled with ten concrete spheres constructed by pouring sand mix into plaster of Paris molds. The diameter of each sphere was approximately 3 in (7.5 cm) with an exposed surface area of 27.6 in^2 (178 cm^2) per ball and 1.94 ft^2 (0.18 m^2) per basket.

With the exception of the first two sample dates (samplers exposed for 32 and 31 days respectively), both baskets were removed from each float every 5 weeks for a period of 8 months. To prevent loss of organisms when removing the basket from the water, a net with mesh of nine openings per centimeter was first placed under and around the basket. The basket and net were then removed from the water together. The basket was removed from the net and placed in a porcelain pan containing a small amount of water. The net was then everted and the organisms were picked off and placed in the pan. The spheres were removed from the basket and placed in another porcelain pan containing a small amount of water. Ninety-five per cent ethyl alcohol was sprayed on each sphere to facilitate removal of the organisms. Each sphere was then brushed clean using a soft-bristled brush. The clean spheres were returned to the basket which was refastened to the float. The contents of the two pans were concentrated using a No. 30 U. S. Standard sieve with openings of 0.0234 in

(0.0595 cm), placed in jars filled with 95% ethyl alcohol and returned to the laboratory.

The organisms were sorted with the aid of phloxine B but the presence of stain on the organisms was determined to be undesirable (Mason and Yevich, 1967). During the latter part of the project, a modified sugar flotation method was utilized for separating organisms from the organic debris (Anderson, 1959). Organisms were sorted from the debris, identified according to order, and preserved in 70% ethyl alcohol. Later, organisms were sorted into operationally defined "species" on the basis of simple external differences such as color, size, and shape and were counted. Specific identification of organisms was not done because of the rationale provided by Wilhm and Dorris (1966), Cairns et al (1968), Mathis and Dorris (1968), and Cairns and Dickson (1971).

This information was used to compute species diversity (diversity per individual) and redundancy; where diversity per individual, $\bar{D}$, represents the average information contributed by individuals to the community and redundancy, R, measures the dominance of one or more species in the community. These methods were used by Patten (1962) in a pollution study, and by Wilhm and Dorris (1966) to statistically analyze benthic macroinvertebrate community structure. Wilhm (1967) proposed the following equation for species diversity:

$$(1) \qquad \bar{D} = \sum_{i=1}^{S} n_i/N \log_2 n_i/N$$

where:

$\bar{D}$ = Diversity per individual, a dimensionless expression

S = Number of species

n_i = Number of individuals per species (in the i^{th} species)

N = Total number of organisms

Equation 1 is an approximation which improves as N and S increase. Since small sample sizes are frequently encountered in nature, the following equation was used for this study (Harkins and Austin, 1971):

$$(2) \qquad \bar{D} = 1/N \left[\log_2 N! - \sum_{i=1}^{S} \log_2 n_i!\right]$$

Redundancy, the measure of dominance of one or more species in the community, was calculated using the formula:

$$(3) \qquad R = \frac{D_{max} - D}{D_{max} - D_{min}}$$

where:

R = Redundancy

$$(4) \qquad D_{max} = \log_2 N! - S \log_2 (N/S)!$$

$$(5) \qquad D = \sum_{i=1}^{S} n_i \log_2 n_i/N$$

$$(6) \qquad D_{min} = \log_2 N! - \log_2 [N - S + 1]!$$

The equation for redundancy will then reduce to:

$$(7) \qquad R = \frac{\sum_{i=1}^{S} \log n_i! - S \log (N/S)!}{\log (N-S+1)! - S \log (N/S)!}$$

$\bar{D}$ and R were reduced to a single index value per sample utilizing a nonparametric discrimination technique (Harkins and Austin, 1971). In order to maintain a constant reference point, a control value of R = 1 and $\bar{D}$ = 0 for the "biological desert" condition was used; the two indices and the control points were ranked from low to high. The new index, standardized distance ($S.D._i$), was computed as:

$$(8) \qquad S.D._i = \frac{(\text{Rank } R_i - \text{Rank } R_c)^2}{\text{Var } (R)} + \frac{(\text{Rank } \bar{D}_i - \text{Rank } \bar{D}_c)^2}{\text{Var } (D)}$$

where:

$i = 2, 3 \ldots M + 1$

M = Number of sample points

This distance is unique. Its magnitude is a measure of the relative "well being" of the sampling station. The larger $S.D._i$, the farther the station is presumed to be from a

"biological desert" condition.

Computations for $\bar{D}$, R and $S.D._i$ were performed on a Honeywell 1200 computer. The $S.D._i$'s were compared using a parametric analysis of variance.

Water velocity was measured at each station with a Type A Price current meter. A Hellige turbidimeter was used to determine the turbidity of water samples collected at the surface of each station. Discharge data was obtained from the U. S. Department of the Interior, Geological Survey, Water Resources Division.

RESULTS

Organisms collected represented eight orders of aquatic insects (Trichoptera, Diptera, Ephemeroptera, Odonata, Coleoptera, Plecoptera, Megaloptera and Hemiptera), four orders of crustaceans (Branchiopoda, Copedoda, Decapoda and Amphipoda), one order of arachnid (Acarina), one class of mollusk (Gastropoda), one order of coelenterate (Hydrariae), one class of roundworm (Nematoda) and the phylum Annelida (including the class Hirudinea). The total number of organisms collected over the sampling period is summarized in Tables 2 and 3. Representatives of the order Trichoptera were the most numerous followed by members of Diptera and Ephemeroptera respectively.

Biological data for all samples is listed in Table 4.

Table 2. Total number of macroinvertebrates collected on artificial substrates from surface samplers, May to December 1971.

Taxa	Stations				
	1(6)*	2(5)	3(7)	4(5)	5(4)
Trichoptera	609	186	2,464	565	5,412
Diptera	635	1,091	888	1,679	3,649
Ephemeroptera	350	235	1,417	380	487
Odonata	1	8	0	30	11
Coleoptera	8	5	16	7	6
Plecoptera	0	4	19	4	0
Megaloptera	0	0	4	1	2
Annelida	423	705	66	383	104
Acarina	29	8	86	11	20
Crustacea	1	22	0	70	0
Others	1	0	31	8	1

*Number in parentheses indicates number of individual samples.

Table 3. Total number of macroinvertebrates collected on artificial substrates from one meter samplers, May to December 1971.

Taxa	Stations				
	1(4)*	2(6)	3(5)	4(7)	5(2)
Trichoptera	481	1,296	1,695	2,579	131
Diptera	375	636	677	1,557	160
Ephemeroptera	282	853	676	899	74
Odonata	2	11	0	37	2
Coleoptera	9	13	0	21	10
Plecoptera	3	9	8	5	0
Megaloptera	0	1	0	1	0
Annelida	718	445	31	295	43
Acarina	28	15	87	95	2
Crustacea	1	9	0	58	0
Others	0	2	0	7	0

*Number in parentheses indicates number of individual samples.

Table 4. Summary of data for macroinvertebrates collected on artificial substrates, May to December 1971, including R (redundancy), $\bar{D}$ (species diversity) and S.D. (standardized distance). St. = Station.

Sample date	St.	Depth of substrate	Number of species	Number of organisms	R	$\bar{D}$	S.D.
5/26	1	Surface	13	376	0.23	2.82	17.99
6/26	1	Surface	--*	---	----	----	-----
7/31	1	Surface	15	461	0.22	3.01	20.05
9/4	1	Surface	17	570	0.38	2.58	7.61
10/9	1	Surface	17	267	0.51	2.17	3.15
11/13	1	Surface	12	362	0.56	1.66	0.98
12/18	1	Surface	5	21	0.20	1.70	10.98
5/26	1	1-Meter	14	393	0.27	2.76	15.67
6/26	1	1-Meter	--	---	----	----	-----
7/31	1	1-Meter	16	657	0.35	2.62	10.75
9/4	1	1-Meter	--	---	----	----	-----
10/9	1	1-Meter	12	230	0.57	1.69	1.00
11/13	1	1-Meter	14	619	0.83	0.81	0.02
12/18	1	1-Meter	--	---	----	----	-----
5/26	2	Surface	11	267	0.31	2.39	8.99
6/26	2	Surface	--	---	----	----	-----
7/31	2	Surface	--	---	----	----	-----
9/4	2	Surface	7	838	0.66	1.00	0.08
10/9	2	Surface	11	336	0.51	1.76	1.87
11/13	2	Surface	17	224	0.49	2.24	4.06
12/18	2	Surface	10	599	0.61	1.36	0.18
5/26	2	1-Meter	13	505	0.33	2.50	9.10
6/26	2	1-Meter	--	---	----	----	-----
7/31	2	1-Meter	17	1,941	0.30	2.85	15.88
9/4	2	1-Meter	8	115	0.59	1.39	0.32
10/9	2	1-Meter	12	119	0.51	1.94	2.19
11/13	2	1-Meter	17	370	0.58	1.89	1.42
12/18	2	1-Meter	12	240	0.59	1.63	0.58
5/26	3	Surface	15	292	0.21	3.04	21.35
6/26	3	Surface	16	1,915	0.35	2.60	10.14
7/31	3	Surface	16	1,962	0.31	2.76	13.27
9/4	3	Surface	18	455	0.44	2.42	5.63
10/9	3	Surface	13	154	0.15	3.02	22.20
11/13	3	Surface	11	196	0.25	2.58	13.34
12/18	3	Surface	6	17	0.55	1.55	0.92

*No sample

Table 4. Continued.

Sample date	St.	Depth of substrate	Number of species	Number of organisms	R	$\bar{D}$	S.D.
5/26	3	1-Meter	10	300	0.17	2.71	18.12
6/26	3	1-Meter	16	2,269	0.37	2.54	7.55
7/31	3	1-Meter	12	552	0.31	2.46	8.87
9/4	3	1-Meter	--	---	----	----	-----
10/9	3	1-Meter	--	---	----	----	-----
11/13	3	1-Meter	8	51	0.68	1.38	0.13
12/18	3	1-Meter	2	2	0.00	0.50	11.55
5/26	4	Surface	14	350	0.30	2.68	13.86
6/26	4	Surface	--	---	----	----	-----
7/31	4	Surface	15	552	0.22	3.01	19.22
9/4	4	Surface	15	1,371	0.50	1.99	2.74
10/9	4	Surface	15	800	0.63	1.53	0.29
11/13	4	Surface	6	65	0.38	1.64	3.00
12/18	4	Surface	--	---	----	----	-----
5/26	4	1-Meter	15	252	0.28	2.81	16.09
6/26	4	1-Meter	21	1,981	0.44	2.48	5.77
7/31	4	1-Meter	19	844	0.34	2.81	12.86
9/4	4	1-Meter	16	1,646	0.35	2.60	8.68
10/9	4	1-Meter	13	723	0.44	2.10	3.73
11/13	4	1-Meter	6	90	0.33	1.75	5.42
12/18	4	1-Meter	9	18	0.35	2.17	5.44
5/26	5	Surface	12	466	0.27	2.60	13.91
6/26	5	Surface	--	---	----	----	-----
7/31	5	Surface	17	686	0.55	1.92	1.82
9/4	5	Surface	18	5,332	0.47	2.21	3.79
10/9	5	Surface	18	3,208	0.47	2.23	4.16
11/13	5	Surface	--	---	----	----	-----
12/18	5	Surface	--	---	----	----	-----
5/26	5	1-Meter	13	259	0.30	2.60	12.16
6/26	5	1-Meter	--	---	----	----	-----
7/31	5	1-Meter	12	163	0.39	2.26	5.35
9/4	5	1-Meter	--	---	----	----	-----
10/9	5	1-Meter	--	---	----	----	-----
11/13	5	1-Meter	--	---	----	----	-----
12/18	5	1-Meter	--	---	----	----	-----

The number of species ranged from 2 to 21 per sample. Generally, species numbers were high in summer and decreased in fall. Number of organisms per sample varied from 2 to 5,332. Organism numbers reached peaks in June, July and September and then declined in the last three sampling months. The number of organisms collected in the surface baskets in September was high for stations 1, 2, 4 and 5 but was relatively low for station 3. Compared with all surface samples, station 3 collected the most organisms in June and July, but collected the fewest in September, October and December. A large number of organisms were collected from station 5 in October. The number of annelids increased during fall at stations 1 and 2. Trichoptera were absent at station 2 on September 4, but were collected in all other samples for all stations. At times, station 2 was in very little if any water current.

The measure of dominance of one or more species in the community, that is redundancy, ranged from 0.00 to 0.83. Redundancy was generally low in spring, increased through summer and leveled off in fall. An expression of the compositional richness of a mixed-species aggregation of organism, $\bar{D}$, varied from 0.50 to 3.04. Species diversity was generally high in spring and summer and then declined in September and the fall months. Standardized distance (S.D.) values ranged from 0.02 to 22.20. In the first three sampling months, S.D. values were generally high, but were low in the remaining

months.

Tables 5 through 9 show the average number of macroinvertebrates per sample for each station. Since statistical analysis of the community structure (S.D.) showed no significant differences between surface and one meter baskets, the taxa counts were added and averaged for each sampling date in Tables 5 through 9. Macroinvertebrates were not collected from stations 1, 2 and 5 in June because the floats were lost in high water. On June 7, 10, 11, 12 and 13 the discharge was over 10,000 cfs which was the highest during the entire sampling project (U. S. Department of the Interior, Water Resources Division, 1972). The original floats that were set in the Des Moines River in April 1971 were anchored by mason foundation blocks. After floats 1, 2 and 5 were lost, the replacement floats were relocated by attaching them to bridge supports. Station 5 was moved a second time after the water level dropped. This could have changed some of the sampling conditions for those stations. Samples were not collected from station 5 in November and December because of vandalism.

Physical data for surface measurements at each station is also presented in Tables 5 through 9. Trends were more definite for physical data than biological data. The range for water temperature was 0.5°C (33°F) to 35.5°C (96°F). Water temperature was measured at different times of the day for different stations except for September 3

Table 5. Average number of macroinvertebrates per sample and physical data for station 1.

Taxa or physical parameter	1971 sampling dates						
	5/26	6/26	7/31	9/4	10/9	11/13	12/18
Trichoptera	136	---***	265	197	8	32	9
Diptera	190	--	52	309	72	33	5
Ephemeroptera	48	--	216	48	10	17	1
Odonata	0	--	0	1	1	1	0
Coleoptera	1	--	4	2	2	1	0
Plecoptera	1	--	1	0	0	0	0
Megaloptera	0	--	0	0	0	0	0
Annelida	8	--	0	7	153	403	6
Acarina	1	--	21	6	1	4	0
Crustacea	0	--	0	0	1	0	0
Others	1	--	0	0	0	0	0
Temperature (^{o}C)	6.0	14.9*	--	26.5	14.5	8.0	0.5
Turbidity (ppm SiO_2)	53	32*	11	11	18	16**	18
Velocity (ft./sec.)	2.43	2.09*	1.44	--	0.45	0.85	--
Discharge (cfs)	4,040	3,520	1,550	410	262	695	700

*July 2, 1971 data measurement
**Estimated value
***No sample

Table 6. Average number of macroinvertebrates per sample and physical data for station 2.

Taxa or physical parameter	1971 sampling dates						
	5/26	6/26	7/31	9/4	10/9	11/13	12/18
Trichoptera	214	-***	1,013	0	2	12	8
Diptera	137	--	238	352	112	49	95
Ephemeroptera	12	--	672	110	14	50	22
Odonata	1	--	0	0	4	4	1
Coleoptera	4	--	3	1	1	2	0
Plecoptera	4	--	0	1	0	1	1
Megaloptera	0	--	1	0	0	0	0
Annelida	13	--	0	14	85	175	288
Acarina	1	--	14	0	0	2	2
Crustacea	0	--	0	0	10	2	3
Others	0	--	0	0	0	1	0
Temperature (°C)	6.5	15.6*	--	28.0	14.0	7.5	1.5
Turbidity (ppm SiO_2)	38	38*	9	10	13	16**	8
Velocity (ft./sec.)	2.78	2.14*	1.35	--	0.08	0.23	--
Discharge (cfs)	4,040	3,520	1,550	410	262	695	700

*July 2, 1971 data measurement
**Estimated value
***No sample

Table 7. Average number of macroinvertebrates per sample and physical data for station 3.

Taxa or physical parameter	1971 sampling dates						
	5/26	6/26	7/31	9/4	10/9	11/13	12/18
Trichoptera	106	1,048	832	48	49	46	1
Diptera	140	366	52	299	63	43	1
Ephemeroptera	20	604	362	62	30	10	4
Odonata	0	0	0	0	0	0	0
Coleoptera	0	0	2	12	1	0	0
Plecoptera	3	2	2	0	1	3	2
Megaloptera	0	0	2	1	0	0	0
Annedida	20	1	1	2	10	20	1
Acarina	8	71	6	1	0	1	1
Crustacea	0	0	0	0	0	0	0
Others	0	0	1	30	0	0	0
Temperature (^{o}C)	6.5	16.5	--**	35.5	18.0	7.5	1.0
Turbidity (ppm SiO_2)	44	13	8	7	24	19*	8
Velocity (ft./sec.)	3.05	2.72	2.14	--	0.29	1.61	--
Discharge (cfs)	4,040	3,520	1,550	410	262	696	700

*Estimated value
**No sample

Table 8. Average number of macroinvertebrates per sample and physical data for station 4.

Taxa or physical parameter	1971 sampling dates						
	5/26	6/26	7/31	9/4	10/9	11/13	12/18
Trichoptera	78	1,096	452	460	22	10	5
Diptera	128	345	28	720	529	38	5
Ephemeroptera	18	439	204	182	6	10	3
Odonata	0	0	0	20	12	0	1
Coleoptera	7	2	4	2	1	0	0
Plecoptera	2	3	1	0	0	0	0
Megaloptera	0	0	1	0	0	0	0
Annelida	64	4	0	122	128	21	4
Acarina	0	91	8	0	0	0	0
Crustacea	2	0	0	1	62	0	0
Others	2	1	1	2	3	0	0
Temperature (^{o}C)	8.0	19.2	---***	32.0	17.5	8.0	--
Turbidity (ppm SiO_2)	42	22	11	24*	15	25**	6
Velocity (ft./sec.)	3.56	1.66	1.05	--	0.14	0.28	--
Discharge (cfs)	4,040	3,520	1,550	410	262	695	700

*Sampled on September 7, 1971
**Estimated value
***No sample

Table 9. Average number of macroinvertebrates per sample and physical data for station 5.

Taxa or physical parameter	1971 sampling dates						
	5/26	6/26	7/31	9/4	10/9	11/13	12/18
Trichoptera	123	-**	26	1,138	2,106	--	--
Diptera	192	--	232	1,962	1,000	--	--
Ephemeroptera	14	--	142	206	43	--	--
Odonata	0	--	5	0	3	--	--
Coleoptera	6	--	1	0	3	--	--
Plecoptera	0	--	0	0	0	--	--
Megaloptera	0	--	0	1	1	--	--
Annelida	26	--	18	7	51	--	--
Acarina	1	--	1	18	1	--	--
Crustacea	0	--	0	0	0	--	--
Others	0	--	1	0	0	--	--
Temperature (^{o}C)	7.5	15.8*	--	28.5	16.5	--	--
Turbidity (ppm SiO_2)	148	28*	26	11	16	--	--
Velocity (ft./sec.)	3.05	0.69*	0.47	--	0.06	--	--
Discharge (cfs)	4,040	3,520	1,550	410	262	695	700

*July 2, 1971 data measurement
**No sample

and 4. The sequence of the sampling routine was usually station 1, 2, 3, 5, 4. Station 4 had the highest temperatures in May and June. Temperatures recorded at the stations for 7 P.M. on September 3 are the values listed in the tables because they were higher than those measured on September 4. The highest temperature reported during the project was 35.5°C at station 3 at 7 P.M. on September 3, 1971. However, at 7 A.M. the next morning, the water temperature at station 3 was 26.0°C (79°F).

Other physical parameters measured were turbidity, velocity and discharge. Turbidity was high in May, low in July and September, increased in October and November, and decreased in December. Ranges for turbidity were from 6 to 148 ppm SiO_2. For stations 1-4 water velocity was also highest in May, decreased until a low was reached in October, and increased in November. Velocity was not measured in September and December. The range was 0.06 to 3.56 ft/sec. Mean surface velocities for stations 1-5 respectively were 1.45, 1.32, 1.96, 1.34 and 1.07 ft/sec. Discharge was likewise high in May, decreased until a low was reached in October, and increased in November and December. Discharge data were measured at the S. E. 14th Street Bridge and therefore do not reflect the water received by the Des Moines River from the tributary between stations 3 and 4 (Four-Mile Creek), and the tributaries between stations 4 and 5 (North River, Middle River and South River). The range of discharge

during the entire exposure of the samplers was 72 cfs on August 28 to 11,600 cfs on June 11 and 12, 1971 (U. S. Department of the Interior, Water Resources Division, 1972).

An analysis of variance of the standardized distance values for the biological data demonstrated that there was a significant difference in S.D. values for sampling dates and location of stations (Table 10). There was no significant difference between S.D. values for surface and one meter samples at each station for each sampling date. Time-station interaction and time-depth interaction were not significant at the 0.05 level.

Mean S.D. values for stations and sampling dates are shown in Tables 11 and 12. A significant difference existed between stations 2 and 3 which had values of 4.06 and 11.09 respectively. Means for sampling dates varied from 3.55 to 14.72. A Scheffe Test for multiple comparisons of means ($F = 25.40$ with 6,9 df) indicated that there was a significant difference at the 0.05 significance level between mean S.D. values for two early sampling dates (May 26 and July 31) compared with the last four sampling dates (September 4, October 9, November 13 and December 18). Tables 11 and 12 also list mean $\bar{D}$ values for stations and sampling dates. The grand mean for all species diversity ($\bar{D}$) values was 2.19.

A test for correlation between water velocity and S.D. value for each sample resulted in a correlation coefficient (r) of 0.486 which is significant at the 0.01 level for 30

Table 10. Analysis of variance summary for standardized distance (S.D.) values.

Source of variation	df	SS	MS	F
Sampling dates	6	1,108.56	184.76	13.97**
Stations	4	344.80	86.20	6.52**
Sampler depth	1	27.60	27.60	2.09
Time-station interaction	24	429.48	17.90	1.35
Time-depth interaction	6	36.07	6.01	----
Residual error	28	370.33	13.23	

**Significant at the 0.01 level.

Table 11. Mean standardized distance (S.D.) values and mean species diversity ($\bar{D}$) values for each sampling station.

Mean value	Stations				
	1	2	3	4	5
S.D.	8.82	4.06	11.09	8.09	6.86
$\bar{D}$	2.18	1.90	2.30	2.30	2.30

Table 12. Mean standardized distance (S.D.) values and mean species diversity ($\bar{D}$) values for each sampling date.

Mean value	1971 sampling dates						
	5/26	6/26	7/31	9/4	10/9	11/13	12/18
S.D.	14.72	7.82	12.01	4.12	4.82	3.55	4.94
$\bar{D}$	2.69	2.54	2.63	2.02	2.06	1.74	1.48

paired samples. This correlation coefficient indicated that $(0.486)^2 \times 100 = 23.6\%$ of the variation in S.D. values was due to the effect of differences in current velocity. The correlation coefficient (r) for temperature and S.D. value was -0.277 for 31 paired samples. This inverse relationship indicated that $(-0.277)^2 \times 100 = 7.7\%$ of the variation in S.D. values was due to the effect of differences in temperature. For turbidity and S.D. value correlation, r was equal to 0.329 for 27 paired samples and r^2 equaled 10.8%. The correlation coefficient (r) for discharge and S.D. value was 0.579 for 51 paired samples and r^2 was 33.5% (significant at 0.01 level). Discharge values for all stations were based on measurements at the S. E. 14th St. Bridge and therefore do not include the volume of water that was added to the Des Moines River by sources between S. E. 14th St. Bridge and Runnells Bridge (Des Moines sewage treatment plant, Four-Mile Creek, North River, Middle River and South River).

To check the effect of velocity on standardized distance (S.D.) values, an analysis of covariance was determined in which S.D. values were adjusted for current velocity (Table 13). When corrected for velocity, there was no significant difference between stations; however, a significant difference still remained for time of year.

Table 13. Analysis of covariance summary for standardized distance (S.D.) values with adjustment for current velocity.

Source of variation	df	SS	MS	F
Sampling dates	6	339.59	56.60	4.13**
Stations	4	116.12	29.03	2.12
Sampler depth	1	24.59	24.59	1.79
Time-station interaction	24	396.34	16.51	1.20
Residual error	27	370.24	13.71	

**Significant at the 0.01 level.

DISCUSSION

Trichoptera were the most numerous taxa collected with Diptera and Ephemeroptera second and third respectively. Kennedy (1971) demonstrated the same results from his study. Gakstatter and Shobe (1970) also found Ephemeroptera, Trichoptera and Diptera in relatively high numbers in the Des Moines River.

No significant difference existed between surface and one meter samples. Artificial substrates serve as colonization sites for the biota that drift in the water and the quality of the sample is dependent on the currents to which the substrate is exposed (Henson, 1965). Waters (1965) demonstrated that organisms drift at all depths in a stream. Turbulence in a stream causes a mixing effect which provides food and oxygen necessary for the organisms at different levels. Cummins (1962) stated that substrate, current velocity and food materials have been shown to be of primary importance in the distribution of benthos. The concrete substrate was a factor that was constant in this study.

Analysis of variance demonstrated that there was a significant statistical difference in the location of stations; however, when this was corrected for current velocity, no significant difference was detected (Table 13). Station 1 had the second highest S.D. mean and the second highest mean current velocity. Of all the stations, station 1 was located

in the shallowest water. On the September sampling date, the surface basket was just touching the stream bottom. Only station 3 had a higher mean current velocity.

Station 2 produced the lowest S.D. mean. The sewage treatment plant effluent may have had some negative effect upon the station; however, low velocity appears to be a major factor which affected the station. Statistical analysis showed a positive correlation existed between variation in S.D. values and the differences in current velocity. This station had the second lowest velocity on the basis of measurements that were taken. At times the float had a tendency to drift behind the bridge support away from a relatively swift current. The fact that no Trichoptera were collected in September can probably be attributed to a lack of current velocity. Caddisflies are filter feeders and are dependent upon current for a source of food.

The highest S.D. mean was demonstrated by station 3. This station also yielded the highest mean current velocity. The decline in numbers of organisms in September when numbers generally increased at other stations might be attributed to the increase in water temperature. Since the water temperature varied from at least 26.0°C to 35.5°C on September 3 and 4, it is reasoned that the organisms were not subjected to high temperatures all the time. The organisms that were present in the September sample may have been the more heat-tolerant forms.

The high S.D. values obtained from samples at station 3 may be accounted for by the high current velocity. Moving water promotes respiration and the uptake of nutrients much more than quiet water of the same content. It is not absolutely but rather physiologically richer in oxygen and nutrients. A current consequently promotes respiration and transport of nutrients (Ruttner, 1963). Scott (1958) concluded that the important factor supporting the benthic communities is not so much the concentration of suspended organic matter but rather the total amount passing a given point in a certain time.

Station 4 possessed the third highest mean S.D. value and the third highest mean current velocity. The float was located in deep water near a pile of brush and logs. This may have prevented the samplers from being exposed to a faster current. Current velocity appeared to be largely responsible for the colonization of invertebrates relative to other stations. Station 5 had the second lowest mean S.D. value and the lowest mean current velocity.

The correlation coefficient for current velocity and S.D. value appears to be a more reliable value than the correlation coefficient for discharge and S.D. value. Discharge values used for all stations were measured at the S. E. 14th Street Bridge. Therefore, the discharge values were not accurate for stations 2-5 because of the water added to the river by the Des Moines sewage treatment plant, Four-Mile

Creek, North River, Middle River and South River. The values for current velocity were measured at each station and therefore are more indicative of the condition at each station than are discharge values. Velocity is a component of discharge, but even though the discharge is the same at any one point in the river, the velocity may differ from shore to midstream and from top to bottom (Leopold, Wolman and Miller, 1964).

After S.D. values were adjusted for current velocity, the analysis of covariance showed that no significant difference existed between stations, but a significant difference remained for sampling dates. This indicates that physical parameters, such as velocity, should be considered in pollution studies which analyze the biota. This study demonstrated that differences in stations were attributed to variations in current velocity. It makes one wonder whether the differences reported in biotic collections of pollution surveys could be eliminated when corrected for differences in physical parameters.

The collection of macroinvertebrates in this study demonstrated seasonal distribution. Kennedy (1971) also showed seasonal distribution in the occurrence of macroinvertebrates collected from the Des Moines River with low numbers in May, high numbers in July, August and September, with decreases through fall. Hynes (1970), in reviewing the literature about seasonal changes in the benthic fauna,

indicated that under normal conditions the numbers of specimens decreased in spring and early summer primarily because of the emergence of adult insects, rises again in late summer and autumn as new specimens hatch from eggs, and then declines during the winter period because of little or no recruitment. The results of this study somewhat differed from Hynes' inference in that numbers were high in early summer and started declining in early fall. Hynes (1970) also stated that species generally occur, or are common, only where their food is readily available. Mackay and Kalaff (1969) found that species diversity values of insect communities were high in summer in a Quebec stream. They suggested that it may have been due to an increased food supply in summer. Seasonal changes in species diversity of the stream also reflected the life history patterns of insects.

The S.D. values obtained in May and July differed significantly from those in September, October, November and December (Table 12). The S.D. value for June was lower than those for May and July. Only three of ten possible samples were collected in June due to the disappearance of three floats (1, 2, 5) and the surface basket at station 4. In addition, many of the organisms collected in June were small specimens, indicating that a new generation had hatched from eggs between the May and June sampling dates. The small size made it difficult to differentiate; therefore it was likely

that during the sorting process, several species may have been sorted as one group which would have resulted in a lowered species diversity.

The mean S.D. value was low in September. Many small organisms were collected in September, indicating a possible second generation hatch between the July and September sampling dates. Again, small organisms would have been hard to distinguish and could have been lumped into one group. Numbers of organisms decreased in fall possibly due to predation and lack of recruitment. Also growth would decrease (Hynes, 1970) and some organisms would go into the pupal state such as Trichoptera and Diptera.

The grand mean for $\bar{D}$, 2.19, included values computed under different conditions, but it does indicate the general quality of the section of the river studied. The grand mean indicates that the Des Moines River is mildly polluted based on empirical considerations of Wilhm and Dorris (1968). Values of $\bar{D}$ usually range from 1 to 3 in areas of moderate pollution. Values less than 1 have been obtained in areas of heavy pollution and values exceeding 3 in clean water.

For all samples, $\bar{D}$ ranged from 0.50 to 3.04. However for all samples there were only four values above 3.00 and two values below 1.00. The mean values of $\bar{D}$ for each station were not proportional to the mean S.D. values. Stations 4 and 5 had the highest $\bar{D}$ values whereas stations 1 and 3 had the highest S.D. values. The difference is due to the

influence of R used in calculating S.D. values. When $\bar{D}$ is low and R is high as in September for the surface sampler at station 2, the resulting S.D. value is low. On the other hand, when $\bar{D}$ is high and R is low, the S.D. is high demonstrated by the October sample for the surface basket at station 4. Mean $\bar{D}$ values were proportional to mean S.D. values for sampling dates except in December.

The use of artificial substrate in a study of this type has certain disadvantages. First, it does not sample directly from the stream bottom, but rather collects organisms from the drift. Second, artificial substrate does not provide all types of habitats as would be found in an aquatic environment. Third, the concrete spheres may have an effect that would permit only certain organisms to colonize them. However, since the conditions were similar at all stations, the results, no matter how biased are comparable.

There has been some disagreement whether or not organisms in the drift are the same as those occurring in the benthos. Anderson and Lehmkuhl (1968) claimed that there is a difference between drift and benthos. Burrowing benthic forms such as Hexagenia sp. were not found in the present study. Anderson and Mason (1968) demonstrated that the Petersen grab collected a larger number of those organisms which normally inhabit the bottom sediments than does the basket sampler. However, the basket sampler collected more species than the Petersen grab. Jacobi (1971)

found that organisms dominant on the natural substrate sampled with the Surber sampler were found to be dominant on the artificial substrates. The artificial substrate used in this study was comparable in size to the rubble that Pennak and Van Gerpen (1947) determined was the most productive substrate. Waters (1972) contends that drift fauna as distinct from the bottom fauna does not exist and that drifting is merely a temporary event in the life of many members of the bottom fauna or other substrate-oriented populations.

One drawback of the use of species diversity and standardized distance as indices of community structure is that they do not take into account the addition or deletion of specific species, but rather evaluate on the basis of total species numbers. For example, if sample A collected 10 species each represented by 10 organisms and sample B collected 10 different species which are not present in sample A, each with 10 individuals, the species diversity would be the same for both samples.

Species diversity based on information theory would be very high in a community where the total numbers would be equally divided among many species. Such a community does not occur because a normal community fits a logarithmic or a lognormal distribution. Hurlburt (1971) attacked species diversity on the grounds that communities having different species compositions are not intrinsically arrangeable in

linear order on a diversity scale. He presented alternative formulas for interpretation of community structure. Whittaker (1965) distinguished two types of diversity. He referred to the species richness in terms of numbers of species in an area as species diversity. The more species that are present, the greater the diversity. A second approach to diversity, the type used in this study, is based on the relative composition of the species in an area. The more equal the distribution, the greater the diversity. Whittaker referred to this interpretation as dominance diversity.

SUMMARY AND CONCLUSIONS

Artificial substrates were used to measure differences in macroinvertebrate species diversity at five stations in the Des Moines River in the metropolitan area of Des Moines to assess water quality. Results showed that members of the insect order Trichoptera were the most abundant organisms collected. An analysis of variance for standardized distance (S.D.) values demonstrated significant difference for sampling dates and location of stations. However, when corrected for current velocity, no significant difference was detected for location of stations, but significance over time was retained.

The following conclusions were drawn from this study:

1. The major factor controlling colonization of macroinvertebrates in this study appeared to be current velocity.
2. Based on the mean species diversity ($\bar{D}$) values obtained in this project, the Des Moines River is mildly polluted in the section studied.
3. Standardized distance (S.D.) values appear to be more meaningful than species diversity ($\bar{D}$) alone in assessing community structure because they are calculated utilizing both $\bar{D}$ and R values and are subject to statistical analysis.
4. Recommendations for future study
   a. Construct a transect across the Des Moines River with artificial substrate samplers to compare colonization of macroinvertebrates with respect to different current velocities at the same location.
   b. Study the drift and compare qualitatively and quantitatively with macroinvertebrates collected on artificial substrates.
   c. Compare grab samples qualitatively and quantitatively with samples from artificial substrates.
   d. Study feeding and reproductive activity of macroinvertebrates during each month of the year.
   e. Follow-up species diversity studies after Saylorville Reservoir is impounded.

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